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ABSTRACT

A model demonstrates how low correlations for academic achievement in separate units of instruction can be compatible with high correlations for cumulated achievement. The unit achievement is assumed to consist of a task-specific part and a part correlated with a predictor. When units of learning are cumulated, attrition of earlier learning takes place according to a certain retention ratio. This paper illustrates how correlations with achievement in other tasks and with a predictor are affected by the cumulation process, using various patterns of parameter values. (Author/MV)

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A NOTE ON THE CORRELATIONS BETWEEN INCREMENTS, CUMULATED ATTAINMENT AND A PREDICTOR

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A NOTE ON THE CORRELATIONS BETWEEN INCREMENTS, CUMULATED ATTAINMENT AND A PREDICTOR

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A note on the correlations between increments, cumulated attainment and a predictor

In the study of attainment in learning tasks, both in laboratory and school situations, it is often found that correlations are low

(A) between gains in a certain unit of instruction and general measures of aptitude,

(B) between gains in different units of instruction, and

(C) between gains and initial level of attainment.

At the same time rather high correlations are observed

(D) between cumulated attainment and aptitude,

(E) between cumulated attainment in different learning tasks, especially when school subjects are concerned, and

(F) between cumulated attainment at different stages of the learning process.

Insert Figure 1 about here

Woodrow (1946) who drew attention to such findings concluded, i.e., that "individuals possess no such thing as a unitary general learning ability" which can "be identified with the ability known as intelligence" (op. cit., p. 148). He interpreted the difference between (A) and (D) above as the result of specific factors operating on gains and a general factor responsible for cumulated attainment from past learning.

Later research (see Cronbach & Snow, 1977, especially pp. 132-133) has failed to support Woodrow's strong conclusions, and shown that they are doubtful for several reasons, e.g., the narrow character of the learning tasks involved and the use of unreliable gain scores in the analysis. In fact, "learning tasks often correlate with each other and

with tested abilities" (Cronbach & Snow, op. cit.m p. 132). But still correlations for small units are low compared to correlations for cumlated attainment, and in studies with low statistical power they might easily (and wrongly) be interpreted as an indication of zero correlation. Low unit correlations may, nowever, be quite compatible with high correlations for cumulated attainment. High correlations can be built up through accumulation of gains over time even when separate units have low correlations between themselves and with a predictor.

In the following a model will be developed, based on simple assumptions about the relations between performances in learning tasks. The type of task that comes closest to the model is one where informational content is acquired in separate units of instruction and then cumulated over a sequence of instructional units. Attainment is tested both directly after each separate unit and cumulatively after a certain number of units. The predictor can be a measure of any individual difference variable that is correlated with the attainment, e.g., past attainment in other learning tasks, ability, interest, socioeconomic background. Certainly, a "mechanical" model such as the one to be presented does not take into account any dynamic relations between "increments" and past learning, e.g., such as those demonstrated in the information-processing approach to learning and memory (cf. Norman, 1969). Even so it might afford some baselines for judging correlations of quantitatively measured attainment.

Model

The attainment (a) of an individual in a separate unit (i) of a learning task is conceived as consisting of a task-specific component (s) and a component correlated with a predictor (x) to the extent of a constant proportion (p) of the predictor's true value (t). The attainment is measured with error b and the predictor with error c.

The attainment of an individual in unit i then can be written

$$a_i = s_i + pt + b_i \qquad (1)$$

The following assumptions are made about means (E), variances (V) and covariances (C).

$E(s) = 1$ $\qquad$ $C(s,t) = 0$

$E(t) = E(b) = E(c) = 0$ $\qquad$ $C(s_i,s_j) = h$

$V(s) = V(t) = 1$ $\qquad$ $C(t,t) = 1$

$V(b) = e$ $\qquad$ $C(s,b) = C(s,c) = C(t,b) =$

$= C(t,c) = C(b,c) = 0$

Then for a group of individuals in a separate learning task the attainment has the mean

$$E(a_i) = 1 \qquad (2)$$

and the variance

$$V(a_i) = 1 + p^2 + e \qquad (3)$$

The predictor has the variance

$$V(x) = 1 + f \qquad (4)$$

When the individuals pass through a progression of units of instruction in a learning task their unit attainments are assumed to be cumulated in an additive way; however, with a successive attrition of the attainment in earlier units so that only a certain proportion of the attainment is retained. More specifically the model makes the following assumptions.

The cumulated attainment (y) of an individual after a certain number (k) of units is a sum of increments, each one, however, reduced to a proportion (q) of the retention of the same unit at the next previous stage of the learning process. Since the error b is an error affecting the measurement of unit attainment, and not affecting the retained attainment as such, it is not assumed to enter the cumulation and attrition process. Instead a third type of error (d) appears in the measurement of cumulated attainment. This error is assumed to have $E(d) = 0$, $V(d) = g$, and to be uncorrelated with all other parameters.

Algebraically expressed the cumulated attainment of an individual then becomes

$$y_k = q^{k-1}(s_1 + pt) + q^{k-2}(s_2 + pt) + \ldots + q^{k-k}(s_k + pt) + d \qquad (5)$$

which can be simplified to

$$y_k = q^{k-1}s_1 + \ldots + s_k + \frac{q^k - 1}{q - 1}\, pt + d \qquad (5a)$$

where $\frac{q^k - 1}{q - 1}$ is the sum of the geometric progression $1, q, \ldots q^{k-1}$.

The average attainment for a group of individuals after k increments becomes

$$E(y_k) = \frac{q^k - 1}{q - 1} \qquad (6)$$

The derivation of variances and covariances is simplified by the use of algorithms in matrix form, like the following one for the variance of the cumulated attainment (y_k). In the example k = 2.

	$q^1 s_1$	$q^0 s_2$	$q^1 pt$	$q^0 pt$	d
$q^1 s_1$	q^2	$q^1 h$	0	0	0
$q^0 s_2$	$q^1 h$	q^0	0	0	0
$q^1 pt$	0	0	$q^2 p^2$	$q^1 p^2$	0
$q^0 pt$	0	0	$q^1 p^2$	$q^0 p^2$	0
d	0	0	0	0	g

This matrix can be summarized in the formula

$$V(y_k) = \left(\frac{q^k - 1}{q - 1}\right)^2 (h + p^2) + \frac{q^{2k} - 1}{q^2 - 1} (1 - h) + g$$

Covariances in Cases A - F

In this section covariances will be derived from the model for the six different cases mentioned in the introduction. These can be used together with the variances (above) for the computation of correlations by means of the standard formula

$$r_{12} = C(1,2) \; / \; \left[V(1)\; V(2)\right]^{\frac{1}{2}}$$

Case A. Between attainment in separate unit and predictor

This is the case where attainment in a separate unit is related to, for instance, scores in an intelligence test. Often the resulting correlation is quite low and may be interpreted as an indication of lack

of relationship between the learning task performance and ability.

In matrix form this case looks like

	s_i	pt	b_i
t	0	p	0
c	0	0	0

$$C(a_i,x) = p \qquad (8)$$

Case B. Between any two increments (before attrition)

In this case the attainments in two units of instruction are compared, each measured directly after the completion of the unit. Such correlations also tend to be quite low.

	s_i	pt	b_i
s_j	h	0	0
pt	0	p^2	0
b_j	0	0	0

$$C(a_i,a_j) = h + p^2 \qquad (9)$$

Case C. Between attainment after k units and increment in unit k + 1

This is the case where initial level in a learning task and increments in the next following unit are correlated -- also a case usually characterized by rather low correlations. For k = 2 this results in the following matrix.

	q^1s_1	q^0s_2	q^1pt	q^0pt	d
s_a	q^1h	q^0h	0	0	0
pt	0	0	q^1p^2	q^0p^2	0
b_a	0	0	0	0	0

$$C(y_k,a_{k+1}) = (h + p^2)\frac{q^k - 1}{q - 1} \qquad (10)$$

Case D. Between attainment after k units and the predictor

This and the following cases where cumulated attainment is involved are the ones for which comparatively high correlations usually have been observed. The derivation matrix still uses k = 2.

	q^1s_1	q^0s_2	q^1pt	q^0pt	d
t	0	0	q^1p	q^0p	0
c	0	0	0	0	0

$$C(y_k,x) = p\,\frac{q^k - 1}{q - 1} \qquad (11)$$

Case E. Between cumulated attainment in two learning tasks that do not overlap

In this case the two tasks are assumed at least to have the predictor in common, possibly also some shared "specificity" which is likely to be the situation with achievement in two different school subjects. Under the assumption that the two tasks (y, z) have different values on p, q and d, and different numbers of units of instruction, the matrix gets the following form (k = 2, m = 3).

	$q_1^1s_1$	$q_1^0s_2$	$q_1^1p_1t$	$q_1^0p_1t$	d_1
$q_2^2s_3$	$q_1^1q_2^2h$	$q_1^0q_2^2h$	0	0	0
$q_2^1s_4$	$q_1^1q_2^1h$	$q_1^0q_2^1h$	0	0	0
$q_2^0s_5$	$q_1^1q_2^0h$	$q_1^0q_2^0h$	0	0	0
$q_2^2p_2t$	0	0	$q_1^1q_2^2p_1p_2$	$q_1^0q_2^2p_1p_2$	0
$q_2^1p_2t$	0	0	$q_1^1q_2^1p_1p_2$	$q_1^0q_2^1p_1p_2$	0
$q_2^0p_2t$	0	0	$q_1^1q_2^0p_1p_2$	$q_1^0q_2^0p_1p_2$	0
d_2	0	0	0	0	0

$$C(y_k, z_m) = (h + p_1 p_2) \frac{q_1^k - 1}{q_1 - 1} \cdot \frac{q_2^m - 1}{q_2 - 1} \qquad (12)$$

Case F. Between cumulated attainment at two different stages of the same learning process

This case differs from the previous one in that the two measures of attainment overlap so that all of the task-specific components of the earlier stage is shared with the measures at the later stage. Here p and q are the same for both sides of the comparison, but errors differ; k is part of m. In matrix form, when k = 2 and m = 3:

	$q^1 s_1$	$q^0 s_2$	$q^1 pt$	$q^0 pt$	d_1
$q^2 s_1$	q^3	$q^2 h$	0	0	0
$q^1 s_2$	$q^2 h$	q^1	0	0	0
$q^0 s_3$	$q^1 h$	$q^0 h$	0	0	0
$q^2 pt$	0	0	$q^3 p^2$	$q^2 p^2$	0
$q^1 pt$	0	0	$q^2 p^2$	$q^1 p^2$	0
$q^0 pt$	0	0	$q^1 p^2$	$q^0 p^2$	0
d_2	0	0	0	0	0

$$C(y_k, y_m) = \frac{(q^k - 1)(q^m - 1)}{(q - 1)^2} (h + p^2) + q^{m-k} \frac{q^{2k} - 1}{q^2 - 1} (1 - h) \qquad (13)$$

Numerical illustrations

The model makes use of a large number of parameters. In order to make illustrations feasible it is necessary to limit each parameter to a few values, preferably in a range so that the resulting correlations are of an order of magnitude that is usually found for the particular cases.

However, even though there exists a wealth of empirical data on correlations between attainments and predictors it is difficult to find direct parallels to the cases treated in the model. Therefore the choice of parameter values will be based on general impressions of the results that have been obtained in empirical studies of a related kind.

Starting with Case A, correlations between ability type predictors and attainment in short units of instruction usually are found in the range .2 - .4. The reliability of such a predictor can be assumed to be in the range .8 - .9. The reliability of the attainment score for a unit is likely to be lower, say in the range .6 - .8. Departing from these values, and using the ratio of true to observed variance for reliability, the three parameters required by the model can be estimated to be in the following ranges: $p = .3 - .5$, $f = .1 - .3$, and $e = .3 - .7$. These values give correlations in Case A varying from .20 to .38.

The correlation between attainments in two short units of instruction in the same learning task (Case B) is likely to be in the same range or somewhat higher. With p and e as above this requires the covariance between task-specific components (h) to be in the range .3 - .5. The resulting correlations then range from .22 to .48.

For the cumulated attainment the retention ratio (q) is required. In Figure 1 the average attainment after k units is shown for $q = 1.0$, .95 and .9 respectively.

Insert Figure 2 about here

The choice cannot be made on empirical grounds, since it is hard to find comparable measurements of cumulated attainment after successive numbers of instructional units. Complete retention (1.0), however, is unlikely and .9 results in low averages for cumulated attainment. Therefore .95 will be used in the illustrations.

For cumulated attainment the model also requires an estimate of error variance (g). It is possible to assume either that g is constant for varying numbers of cumulated units which means that reliability grows with k, or that the reliability is constant which means that g grows with k, or some compromise between these alternatives. Here g is chosen so that the resulting reliabilities roughly fall in the range of .6 - .8 for k = 10, and .8 = .9 for k = 30. This corresponds to values of g in the range of 10 to 20, which in the extreme combinations of p, e and h give reliabilities between .60 and .84 for k = 10, and between .84 and .95 for k = 30.

Finally the number of cumulated units has to be chosen. In the illustrations k and m are set to 10, 20 and 30 respectively.

Insert Table 1 about here

Summing up, the illustrations will use all combinations of the parameter values shown in Table 1, including zero values for errors simulating the situations where correlations are corrected for attenuation, as well as zero value for h, i.e., when task-specific components are uncorrelated.

The correlations that result for Cases A - F are shown in Appendix Tables A - F. In general, the correlations increase with increasing values on p, h, k and m, and they decrease with increasing values on the error terms. In Case D, however, increasing values on h have a decreasing effect on the correlation between attainment and predictor.

Instead of commenting on the tables, one at a time, we will compare the different cases for a set of plausible parameter values that result in low and fairly equal correlations for Cases A and B. In order to meet this requirement it turned out to be necessary to use some intermediate combinations of values not represented in Tables A - F.

First all variables are assumed to be measured without error (Table 2, part I).

Insert Table 2 about here

For the given combination of values a correlation between predictor and attainment in a separate unit becomes .29 (Case A). When units are cumulated this correlation grows to .49 with 10 units and .53 with 30 units (Case D) -- a moderate rather than a high correlation. Attainments in two separate units correlate .27 (Case B). When units are cumulated the correlation between attainment, as cumulated from 10 to 30 units, and the immediate attainment in the next following unit becomes .46 - .49 (Case C) which is slightly lower than that between cumulated attainment and a predictor. When cumulated attainment in two sets of non-overlapping units are compared the correlation increases to .78 - .90

(Case E). It increases further in the case of overlap, i.e., when the smaller set of units forms part of the larger, to .88 - .94 (Case F).

All these correlations are reduced when measurement errors are introduced (Table 2, Part II), but relatively less so, for the present configuration of parameter values, for cumulated attainment than for attainment in separate units.

Discussion

This note set out to demonstrate a mechanism that makes high correlations for cumulated attainment compatible with low correlations for attainment in limited units of a learning task. This was clearly shown for the correlations between attainments in the separate units (Case B) as compared with those for cumulated attainments (Case E). The difference was substantial also in the correlations between attainment and a predictor (Case A vs. Case D) although less striking within the range of the parameter values used in the illustrations.

As stated in the introduction the model is based on simple assumptions. In order to make it more realistic it could be developed in various ways. For instance the retention ratio (q) could be made to vary between individuals as a function of the true predictor score (t). The retention ratio could also be made to vary over time, indicating, say, a comparatively larger attrition in the first stages after the learning of a unit than for attainment surviving these early stages. It would also be possible to design experiments to test various assumptions and to afford more realistic estimates of the parameter values. Even so the

model would remain highly mechanistic and the additional work might not add much to the conclusions already drawn about the compatibility of low correlations for unit scores with high correlations for cumulated attainment.

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Norman, D.A. Memory and attention. New York: Wiley, 1969.

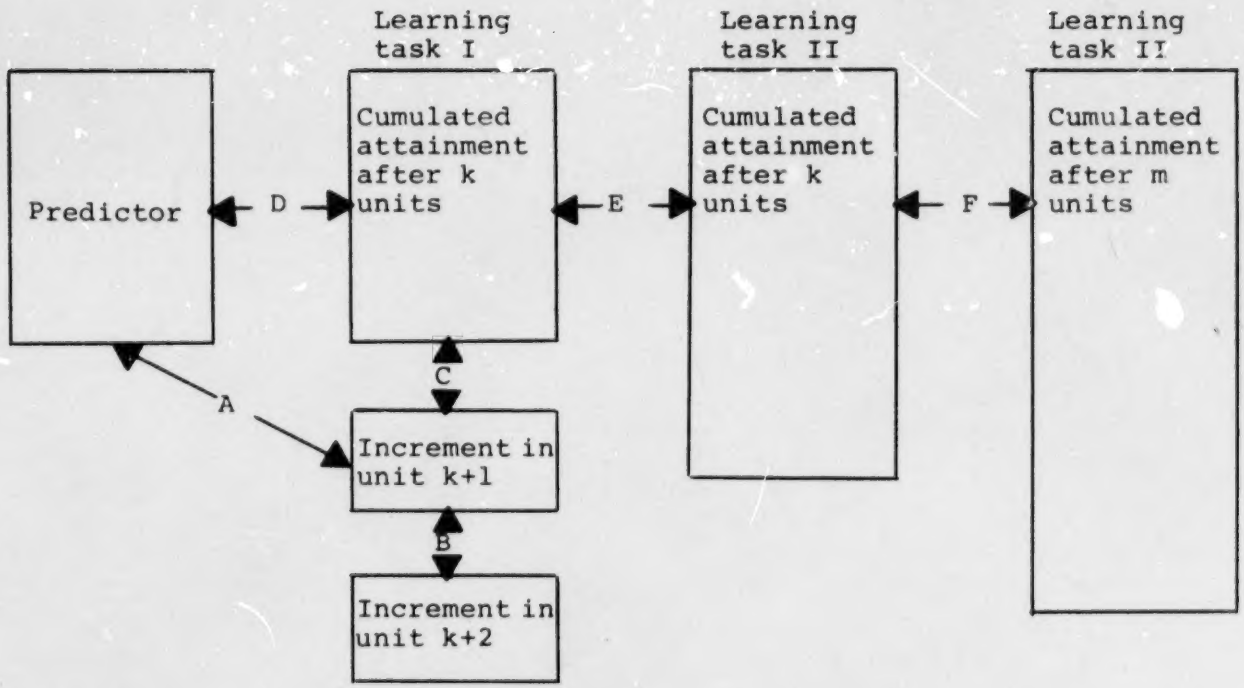
Woodrow, H. The ability to learn. Psychological Review, 53, 1946, 147-158.

Table 1. Parameter values for numerical illustrations.

e	f	g	h	p	q	k	m
.0	.0	0	.0	.3	.95	10	10
.3	.1	10	.3	.5		20	20
.7	.3	20	.5			30	30

Table 2. Comparison of Cases A - D for selected values of parameters.

k	1	10	20	30	10	10	10	20	20	30
m	-	-	-	-	10	20	30	20	30	30
I. p = .3, h = .2, error terms = 0										
Case A	.29									
B	.27									
C		.46	.48	.49						
D		.49	.52	.53						
E					.78	.82	.84	.86	.88	.90
						.90	.88		.94	
II. p = .3, h = .2, e = .5, f = .1, g = 10										
Case A	.21									
B	.18									
C		.32	.36	.38						
D		.39	.45	.47						
E					.55	.63	.66	.73	.76	.80
F						.70	.70		.82	



Figur 1. Relations studied in Cases A - F.

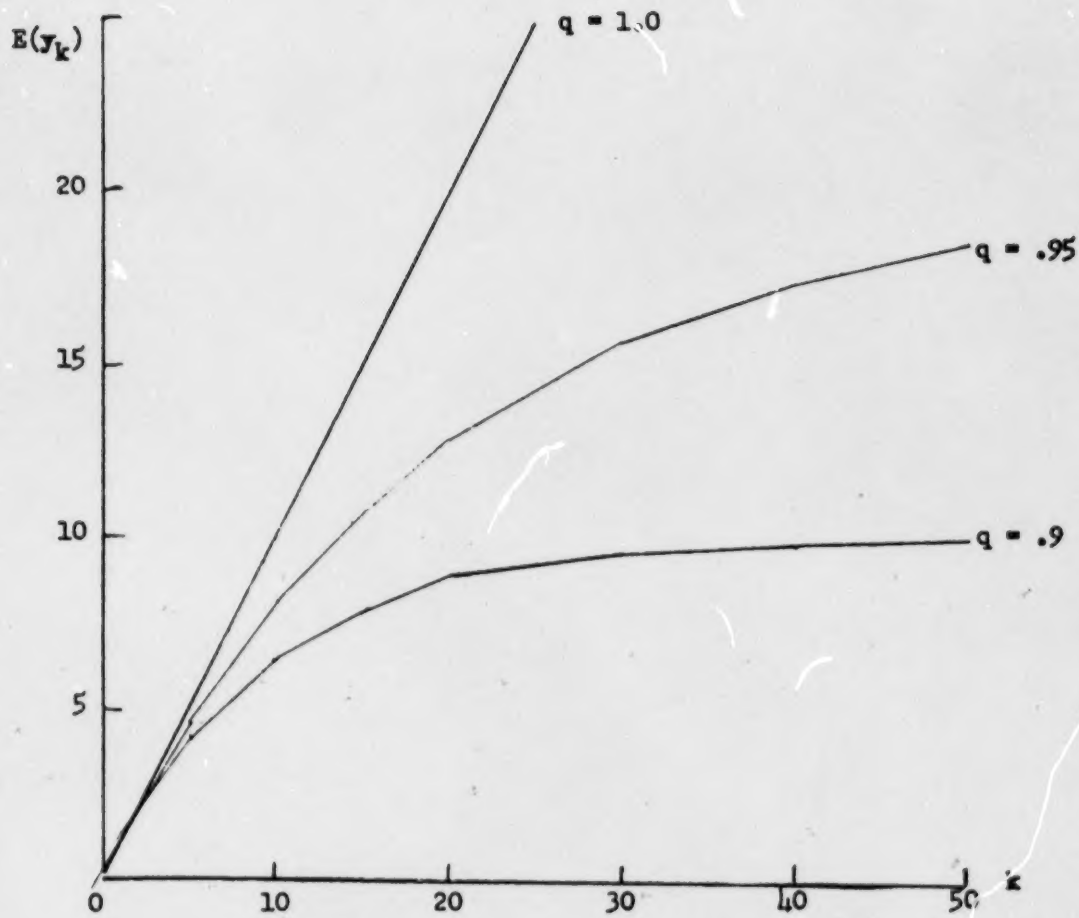


Figure 2. Average attainment after k increments.

Table A. Case A: Correlations between increment and predictor.

	p	.5			.3	
f	e	.0	.3	.7	.0	.3	.7
.0		.45	.40	.36	.29	.25	.22
.1		.43	.38	.34	.27	.24	.21
.3		.39	.35	.31	.25	.22	.20

Table B. Case B: Correlations between two increments.

h	p e	.5 .0	.5 .3	.5 .7	.3 .0	.3 .3	.3 .7
.5		.60	.48	.38	.58	.42	.33
.3		.44	.36	.28	.36	.28	.22
.0		.20	.16	.13	.08	.06	.05

Table C. Case C: Correlations between attainment after k units and increment in unit k+1.

k	h	g	p e	.5 .0	.5 .3	.5 .7	.3 .0	.3 .3	.3 .7
10	.5	0		.75	.67	.60	.71	.62	.55
		10		.69	.62	.55	.63	.56	.50
		20		.64	.57	.51	.58	.51	.45
	.3	0		.62	.56	.50	.55	.49	.43
		10		.56	.50	.45	.48	.42	.37
		20		.51	.46	.41	.42	.38	.33
	.0	0		.38	.34	.30	.20	.17	.15
		10		.32	.28	.25	.15	.13	.11
		20		.28	.25	.22	.12	.11	.10
20	.5	0		.76	.68	.61	.72	.64	.56
		10		.73	.66	.59	.69	.61	.54
		20		.71	.64	.57	.66	.58	.51
	.3	0		.64	.58	.51	.57	.50	.44
		10		.61	.55	.49	.53	.47	.42
		20		.58	.52	.47	.50	.45	.39
	.0	0		.41	.36	.32	.23	.20	.18
		10		.37	.33	.30	.19	.17	.15
		20		.34	.31	.28	.17	.15	.13
30	.5	0		.76	.69	.61	.72	.64	.56
		10		.74	.67	.60	.70	.62	.55
		20		.73	.65	.58	.68	.60	.53
	.3	0		.65	.58	.52	.58	.51	.45
		10		.63	.56	.50	.55	.49	.43
		20		.61	.54	.48	.53	.47	.41
	.0	0		.42	.37	.33	.24	.21	.19
		10		.39	.35	.31	.21	.18	.16
		20		.37	.33	.29	.19	.17	.15

Table D. Case D: Correlations between cumulated attainment and predictor.

			p	.5			.3	
k	h	g	f	.0	.1	.3	.0	.1	.3
10	.0	0		.84	.80	.74	.68	.65	.60
		10		.70	.67	.62	.51	.49	.45
		20		.61	.58	.54	.42	.40	.37
	.3	0		.63	.60	.56	.44	.42	.39
		10		.57	.54	.50	.38	.36	.34
		20		.52	.49	.45	.34	.33	.30
	.5	0		.56	.53	.49	.38	.36	.33
		10		.51	.49	.45	.34	.32	.30
		20		.47	.45	.42	.31	.29	.27
20	.0	0		.91	.87	.80	.79	.75	.69
		10		.83	.79	.73	.66	.63	.58
		20		.77	.73	.67	.58	.56	.51
	.3	0		.65	.62	.57	.46	.44	.40
		10		.62	.59	.54	.43	.41	.38
		20		.59	.57	.52	.40	.39	.36
	.5	0		.57	.54	.50	.38	.36	.34
		10		.55	.52	.48	.36	.35	.32
		20		.53	.50	.46	.35	.33	.31
30	.0	0		.93	.88	.81	.83	.79	.73
		10		.87	.83	.76	.73	.69	.64
		20		.82	.78	.72	.65	.62	.57
	.3	0		.66	.63	.58	.46	.44	.41
		10		.64	.61	.56	.44	.42	.39
		20		.62	.59	.54	.42	.40	.37
	.5	0		.57	.54	.50	.38	.37	.34
		10		.56	.53	.49	.37	.35	.33
		20		.54	.52	.48	.36	.34	.32

Table E. Case E: Correlations between cumulated attainment in two non-overlapping learning tasks ($p_1 = p_2 = p$; $q_1 = q_2 = .95$; $d_1 = d_2 = d$; $h_1 = h_2 = h_{12}$)

			p	.5			.3	
k	m	g	h	.5	.3	.0	.5	.3	.0
10	10	0		.94	.89	.71	.92	.85	.47
		10		.78	.71	.49	.74	.63	.26
		20		.68	.59	.38	.62	.51	.18
10	20	0		.95	.91	.76	.94	.88	.54
		10		.84	.78	.58	.80	.71	.34
		20		.75	.68	.47	.70	.60	.25
10	30	0		.96	.92	.78	.94	.89	.57
		10		.85	.79	.61	.82	.73	.37
		20		.77	.70	.50	.73	.63	.28
20	20	0		.96	.94	.82	.96	.91	.62
		10		.90	.85	.68	.87	.80	.44
		20		.84	.78	.59	.80	.71	.34
20	30	0		.97	.94	.84	.96	.92	.66
		10		.91	.87	.72	.89	.82	.48
		20		.86	.80	.63	.83	.74	.38
30	30	0		.98	.95	.86	.97	.93	.69
		10		.93	.89	.76	.91	.85	.53
		20		.88	.84	.68	.85	.78	.43

Table F. Case F: Correlation between cumulated attainment in two overlapping learning tasks (k part of m)

k	m	g	p h	.5 .5	.5 .3	.5 .0	.3 .5	.3 .3	.3 .0
10	20	0		.98	.96	.88	.97	.94	.77
		10		.86	.81	.67	.83	.76	.48
		20		.77	.71	.54	.73	.64	.35
10	30	0		.97	.94	.84	.96	.92	.69
		10		.86	.81	.66	.83	.76	.45
		20		.78	.72	.54	.74	.65	.33
20	30	0		.99	.98	.93	.98	.97	.85
		10		.93	.90	.80	.91	.86	.62
		20		.87	.83	.70	.84	.78	.49

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